TITLE OF INVENTION

Adhesive Syst m f r Optical Devices

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application is a Continuation-In-Part of Serial Number 10/217,178, filed on August 12, 2002.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

[0002] Not Applicable

BACKGROUND OF THE INVENTION

1. Field of Invention

[0003] This invention pertains to an adhesive system for optical devices. More particularly, this invention pertains to fiber optical devices, such as those used for switching fiber optic cables, and securing optical components or elements in a housing such that misalignment of the components due to environmental changes is minimized.

2. Description of the Related Art

[0004] Fiber optic systems typically require fiber optic elements, such as switches and couplers, to perform the desired operations of the system. Because of this, it is common for a fiber optic system to include at least one fiber optic element. However, associated with the inclusion of fiber optic elements is the undesired characteristic of insertion loss. Insertion loss is the loss of signal power due to the insertion of a device into a transmission line. More particularly, an optical signal has greater signal power when it enters a fiber optic element than it does when it leaves the fiber optic element. Although, insertion loss is unavoidable when incorporating fiber optic elements into a fiber optic system, the displacement or misalignment of fiber optic elements, such as collimators and actuators, within

the fiber optic element induces unnecessary insertion loss. The displacement or misalignment of fiber optic elements causes an optical signal to travel a path slightly altered from the designed signal path. The altered path prevents a receiving collimator from receiving a robust signal, and in extreme conditions, the receiving collimator receives no signal.

[0005] Fiber optic elements are typically secured within the housing of a fiber optic element by way of epoxy resin. Epoxy resin, commonly referred to as epoxy, is a flexible, usually thermosetting resin made by the copolymerization of an epoxide with another compound having two hydroxyl groups and is typically used for adhesives. Conventionally, a fiber optic element is secured within the housing of a fiber optic element by first inserting the element into a corresponding port that is defined by the housing. The port is sized slightly larger than the element and shares the same general shape of the element. After being inserted into the port, the element is aligned for designed operation. Epoxy is then applied around the outer surfaces of the element and the inner surfaces of the port such that a layer of epoxy is disposed between the element and the housing, thus securing the element within the housing. The epoxy is then cured by exposing the epoxy to the light from an ultraviolet wand. During the process of curing, the epoxy expands and contracts and displaces the corresponding fiber optic element from its designed position. The displaced element causes a corresponding optical signal to travel the previously discussed altered path. Additionally, epoxy expands and contracts in response to thermal variations. Therefore, exposure to thermal variation further displaces the fiber optic element.

[0006] Another limitation of conventional fiber optic elements is the difficulty they present regarding the application of epoxy. Once a fiber optic element is inserted into its corresponding port, the remaining space in which the epoxy is applied is very limited and difficult to access. This causes the application of the epoxy to be cumbersome and sometimes insufficient. Similarly, curing the epoxy that has been applied within the confined space offered by conventional elements is cumbersome and sometimes insufficient. Additionally, because conventional methods and devices confine the epoxy between an element and the housing of a

fiber optic element, as the epoxy expands under thermal stimulation, it has potential to break the housing, the element, or both.

[0007] For example, United States Patent Number 5,133,030, titled "Fiber Optic Switch," issued to Lee on July 21, 1992, discloses the conventional method of adhering optical elements. Lee discloses using an adhesive to secure optical fibers **F1**, **F2** within a ferrule **M** by filling the gap between the fibers **F1**, **F2** and the ferrule **M** with adhesive.

BRIEF SUMMARY OF THE INVENTION

[0008] An adhesive system for optical elements is provided. The adhesive system secures optical elements to a housing or substrate in an aligned position and is not intended to be within the optical path. The adhesive system includes an optical element, typically cylindrically shaped, but it may have planar surfaces, and a housing or substrate to which the optical element is to be secured or fixed. The housing has an opening for receiving the optical element and longitudinal slots positioned on opposing sides of the optical element opening and having the longitudinal axis parallel to the longitudinal axis of the optical element. The optical element is aligned relative to the housing and an adhesive joins the slot walls to the optical element.

[0009] For the embodiment where the optical element is secured to a substrate, the substrate has two substantially parallel surfaces substantially perpendicular to the surface of the optical element and oriented parallel to the longitudinal axis of the optical element. The optical element is aligned relative to the substrate and an adhesive joins the substrate surfaces to the optical element.

[0010] In another embodiment, for cylindrical optical elements, a pair of slots or openings in the housing or substrate are substantially diametrically opposed relative to the optical element. In this manner, the adhesive along opposite sides of the optical element maintain the alignment of the element as the temperature and other environmental conditions vary.

[0011] In one embodiment, the adhesive is an epoxy with amorphous silica filler. The uncured adhesive has high viscosity and does not easily wick or flow into crevices or cracks. In one embodiment, the viscosity of the adhesive is at least 5000 centipoise. In one embodiment the amorphous silica is substantially spherical particles, in another embodiment the amorphous silica is substantially angular, or irregularly shaped, particles, and in still another embodiment, the amorphous silica is a combination of spherical and angular particles. In one embodiment, the filler has a concentration equal to or greater than 68%. As the epoxy shrinks during curing, the amorphous silica particles come into direct contact with other amorphous silica particles forming a compacted rigid structure, and the particles are placed under compression by the shrinking epoxy.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

[0012] The above-mentioned features of the invention will become more clearly understood from the following detailed description of the invention read together with the drawings in which:

Figure 1 illustrates an exploded perspective view of one embodiment of a fiber optic device;

Figure 2 is a perspective view of the fiber optic device illustrated in Figure 1;

Figure 3 is a cross-sectional view of a fiber optic element and slotted housing;

Figure 4 is an illustration of lateral offset between two optical elements;

Figure 5 is a chart illustrating the relationship of lateral offset to insertion loss;

Figure 6 is a perspective view of a test device made of in-line collimators assembled in accordance with the present invention;

Figure 7 is a chart illustrating the results of a temperature soak test;

Figure 8 is a chart illustrating the results of a temperature cycle test; and

Figure 9 is a flow chart of one embodiment for the method of adhering.

DETAILED DESCRIPTION OF THE INVENTION

[0013] An adhesive system for fixing an optical element within an optical device is disclosed. An adhesive is applied to an optical device and a slotted housing in such a manner as to minimize displacement of the optical element during curing and as the ambient temperature varies. A 1x2 or 2x1 optical switch **110** is used as one example of the adhesive system.

[0014] Figure 1 illustrates an exploded view of a 1x2 or 2x1 optical switch **110**. The switch **110** includes a housing, or body, **102**, three mirrors **104**, an actuator **106**, and three collimators **108**. In one embodiment the actuator **106** is a bistable device that interjects a mirror into the optical pathway that travels from one collimator **108A**, is reflected by two mirrors **104**, and travels into a second collimator **108C**.

[0015] Visible in Figure 1 are the slots **112** through which an adhesive is applied. The slots **112** are longitudinally oriented with respect to the optical elements, for example the actuator **106** and the collimators **108**. In one embodiment, the slots **112** have rounded ends with long sides. In another embodiment, the slots **112** are rectangular.

[0016] Figure 2 illustrates the optical switch **110** as an assembled unit. The 1x2 switch **110** receives an optical signal through one collimator **108A** and the optical signal is output through another collimator **108C** by reflecting the optical signal with two of the mirrors **104**. With the actuator **106** in an extended position with a mirror introduced into the optical path, the optical signal is redirected from one collimator **108A** to another collimator **108B** by a mirror attached to the actuator **106**. In another embodiment, the switch **110** is a 2x1 switch in which an optical signal through a first collimator **108A** passes through a second collimator

108C unless the actuator **106** extends a mirror and routes a second optical signal from a third collimator **108B** to the second collimator **108C**.

[0017] In another embodiment of the optical device, the device has two collimators **108** and two mirrors **104** for directing an optical signal from one collimator **108A** to the second collimator **108C**. The actuator **106** includes an attenuator, which the actuator **106** controls. In one embodiment, the attenuator is interjected into the optical path of the optical signal. In another embodiment, the attenuator is a variable attenuator in which the level of attenuation is selectively controlled by the actuator **106**.

[0018] With optical devices, the precision with which the optical path is directed affects the performance of the device. It is desirable to minimize any displacement of any of the optical elements relative to other elements. Further, it is desirable that the alignment of the optical elements remain stable over widely varying environmental conditions, including temperature and humidity. In prior art devices, displacement occurs when the environmental conditions, including ambient temperature, varies over a relatively small range.

[0019] Figure 3 illustrates a cross-section of a portion of the housing **102** and a collimator **108**. Those skilled in the art will recognize that the collimator **108** and the actuator **106** are considered optical elements, and that the set of optical elements includes other elements than just the collimator **108** and the actuator **106**. For illustration purposes, with respect to the adhesive system the terms are used interchangeably when referring to an element being adhered to a housing **102** or substrate. Further, in describing the adhesive system, the optical elements and housing may be variously described, interchangeably, as members. In other words, in one embodiment the optical element **108** is a first member and the housing **102** is a second member. In another embodiment, the housing **102** is a first member and the optical element **108** is a second member. In both embodiments the first member includes an opening for receiving the second member, and the first member has slots into which adhesive is introduced. In still another embodiment, the housing **102** is formed in two pieces, or substrates, adapted to mate with the optical element **108**. The substrates have a gap or space

between them into which an adhesive **302**, **304** is placed. (See Figure 6 for an example of this embodiment.) Also, the housing **102** and substrates **602**, **604** are support members.

[0020] The optical element **108** loosely fits into an opening in the housing **102**, as shown by the gap **306** between the housing **102** and the optical element **108**. Two slots **112A**, **112B** are located in the housing **102** on diametrically opposed sides of the optical element **108**. An adhesive **302**, **304** connects the housing **102** to the optical element **108** by bridging the distance between two walls **312**, **314** of the slot **112** and attaching to the optical element **108**.

[0021] The adhesive has a high viscosity, which prevents the adhesive from flowing into the gap **306** between the housing **102** and the optical element **108**. A viscosity equal to or greater than 5000 centipoise, when used with the gaps **306** typically found in optical elements **108**, is sufficient to prevent the adhesive flowing, or wicking, into the gap **306**. In one embodiment, the adhesive has a viscosity of 12,000 to 15,000 centipoise. The gap **306** is sized to allow the optical element, which in the illustrated embodiment is a optical element **108**, to be moved within the housing **102** to align the optical element to minimize insertion loss. Once the optical element **108** is aligned, the adhesive **302**, **304** is applied and cured. Because of the low shrinkage and thermal stability of the adhesive **302**, **304**, in combination with the arrangement of the slots **112** with respect to the optical element **108**, the element's **108** alignment is maintained after curing and during operation.

[0022] In one embodiment, a UV curable adhesive is selected. In another embodiment, the transition point of the adhesive **302**, **304** is outside the operating temperature range, which enhances the dimensional stability of the optical device **110**. In still another embodiment, keeping the transition point outside the operating range is accomplished by using fillers. In an embodiment of the adhesive with a filler, when the epoxy is cured, the filler is placed in compression. The filler, in one embodiment is amorphous silica, which can be spherical or angular or a combination of the two. The filler is blended with the adhesive to form an admixture having a concentration of between 60 to 84% filler, with concentrations

between 68 and 80% filler showing very good results. Epoxy normally experiences approximately 20% shrinkage when cured. When the epoxy with filler is cured, the filler granules come into direct contact with each other, resulting in compressive forces being applied to the filler as the epoxy shrinks. The amorphous silica experiences very little shrinkage or expansion under ambient temperature ranges and is a window to ultraviolet light, so that it does not interfere with the curing process for the adhesive. Amorphous silica is also relatively inert chemically and thermally, and it can withstand significant compression stress and is available at reasonable cost. Those skilled in the art will recognize that other materials with properties similar to amorphous silica can be used without departing from the spirit and scope of the present invention.

[0023] In one embodiment, the amorphous silica has a crystalline content of less than 0.5%. At 99.5% purity of amorphous silica the morphology is stable. As impurities increase in the amorphous silica, the temperature related properties suffer because of the manufacturing techniques that result in increased crystalline content with increased impurities. A typical lower limit of purity would be approximately 98%; however, purity of approximately 96% may be acceptable based on the chemical content of the impurities.

[0024] In another embodiment, the amorphous silica has an average particle size less than 10 micrometers. Epoxy with amorphous silica filler of at least 68% concentration of filler experiences less than 0.1%, oftentimes between 0.04 to 0.05% during testing, linear shrinkage during curing. Further, thermal expansion/contraction is limited to less than 100ppm per degree Celsius, typically 6 to 60ppm, over a temperature range of -40 to +85 degrees Centigrade.

[0025] The configuration illustrated in Figure 3 has certain features that result in a stable configuration. In particular, after the optical element **108** is positioned and aligned, the adhesive **302**, **304** is applied and cured with very little shifting of the optical element **108** relative to the housing **102** occurring as a result of the curing. The adhesive **302**, **304** adheres to the sidewalls **312**, **314** of the longitudinal slot **112** and to the optical element **108**. The surface of the adhesive **302**, **304** opposite the optical element **108** is exposed to the environment and is

free to contract from shrinkage during curing and to expand due to thermal expansion.

[0026] The adhesive **302, 304**, as it cures, shrinks, which causes tension forces to be applied to the slot **112** side walls **312, 314**. Further, because of the opposing slots **112A, 112B**, as the adhesive shrinks during curing, the optical element experiences tension between the two applications of adhesive **302, 304**. These tension forces are small because, during curing, the adhesive **302, 304** shrinks only a small amount. In testing, good performance of the adhesive connection was found when the slot **112** had a longitudinal axis aligned with the longitudinal axis of the optical element **108**, and the slot's longitudinal axis was substantially longer than the width of the slot **112**. The joint, or seam, formed by the adhesive **302, 304** bridging the gap **306** adjacent the slot side walls **312, 314** and the surface of the optical element **108** is longer when the slot **112** has a long longitudinal axis. The joint extending along the longitudinal axis of the optical element **108** aids in maintaining the alignment of the optical element **108** relative to the housing **102**.

[0027] In another embodiment, the adhesive system includes an optical element **108**, a housing **102** or substrate with a single slot **112**, and adhesive **302** in that slot **112A** bridging the area between the slot walls **312, 314** and the optical element **108**. In this embodiment, the optical element **108** is either cylindrical or planar, for example, a mirror, and there is no gap **306** between the optical element **108** and the housing **102** or substrate. The adhesive **302** in the slot **112A** fixes the optical element **108** to the housing **102** or substrate such that the optical element is not displaced relative to the housing **102** or substrate during curing or temperature variations. The mechanism that obtains this stability in this embodiment differs from the mechanism for the illustrated embodiment. In this embodiment, the shrinkage of the adhesive **302** applies tension between the walls **312, 314** of the slot **112A** and between the adhesive **302** and the optical element **108**. The tension between the adhesive **302** and the optical element **108** creates a compressive force between the optical element **108** and the housing **102** or substrate at the area where they are in contact. As long as the compressive force

remains as the adhesive experiences temperature variations, the optical element **108** will maintain dimensional stability relative to the housing **102** or substrate.

[0028] In one embodiment, the adhesive **302**, **304**, in combination with the slots **112A**, **112B** function to adhere the optical element **108** to the support member **102**. In another embodiment, the adhesive **302**, **304** with an amorphous silica filler, in combination with the slots **112A**, **112B** function to adhere the optical element **108** to the support member **102**. In still another embodiment, the adhesive **302**, in combination with the slot **112A** function to adhere the optical element **108** to the support member **102** when the optical element **108** and the support member **102** are in contact. In yet another embodiment, the adhesive **302** with an amorphous silica filler, in combination with the slot **112A** function to adhere the optical element **108** to the support member **102** when the optical element **108** and the support member **102** are in contact.

[0029] Figure 4 illustrates how an optical signal **420** can be misaligned between two collimators **402**, **412**. The optical signal **420** originates from a first collimator **402**, which receives the signal **420** from a source. In an optimal configuration, the centerline of the optical signal **420** is aligned with the centerline **424** of a second collimator **412**. In the illustrated example, the optical signal **420** has a lateral offset **422** relative to the second collimator **412**, resulting in an insertion loss, which is typically expressed in decibels (dB).

[0030] Figure 5 illustrates a chart that plots lateral offset **422** against insertion loss. The offset curve **502** shows a minimum insertion loss when there is no lateral offset **422**. As the lateral offset **422** increases, with the increases shown as micrometers (μm), the insertion loss increases.

[0031] Figure 6 illustrates a test device **610** that includes a pair of collimators **402**, **412** aligned and secured with adhesive **612**, **614**. A first substrate **602** is placed in direct contact with the first collimator **402** and the second collimator **412**. A second substrate **604** is positioned opposite the first substrate **602** and in direct contact with the first collimator **402** and the second collimator **412**. With the collimators aligned **402**, **412** such that the optical signal

422 has no lateral offset **422**, adhesive **612**, **614** is applied between the two substrates **602**, **604** at the seams defined by the direct contact of the substrates **602**, **604** and the collimators **402**, **412**. Although only one side of the test device **610** is shown, adhesive is applied between the substrates **602**, **604** on the non-visible side, also. The adhesive **612**, **614** is cured with an ultraviolet wand.

[0032] Figure 7 charts the results of a soak test that involved heating the test device **610** to a temperature **702** for a specified time and showing the insertion loss over time as the temperature varies. Additionally, in order to fully illustrate the performance, a conventional-type device was subjected to the same test. The conventional-type device was constructed of two collimators **402**, **412** inserted in opposite ends of a cylindrical tube with the adhesive applied between the aligned collimators **402**, **412** and the cylindrical tube.

[0033] In Figure 7, a temperature curve **702** is shown in terms of Celsius degrees with respect to time. A test device curve **706** represents the performance of the test device **610** and is shown in terms of insertion loss with respect to the temperature curve **706** and time. A conventional device curve **704** represents the performance of the conventional-type device and is shown in terms of insertion loss with respect to the temperature curve **706** and time. In the chart of Figure 7, insertion loss is evaluated in terms of decibels (dB) and time is evaluated in terms of minutes (min).

[0034] The test device curve **706** reveals less initial insertion loss than the conventional device curve **704** as indicated by the insertion loss values at zero minutes and ambient temperature. However, as the temperature was increased to 85 degrees Celsius, the test device curve **706** maintained a substantially consistent insertion loss value while the conventional device curve **704** indicated an increase in insertion loss. The temperature was raised to 120 degrees Celsius and the test device curve **706** maintained a substantially consistent insertion loss value while the conventional device curve **704** indicated a further increase in insertion loss. Finally, the temperature was raised to 130 degrees Celsius where the oven shutdown. As the temperature dropped after the shutdown, the conventional device curve **704** indicated a drop in insertion loss. However, the test device curve

706 maintained a substantially consistent insertion loss value relative to the conventional device curve **704**.

[0035] The results of the soak test reveal that fiber optic devices constructed in accordance with the test device **610** introduce less insertion loss to a fiber optic system than fiber optic devices assembled in a conventional manner. This is seen by the initial insertion loss values, which indicate the test device **610** better limits the negative effects of epoxy during a cure than do conventional devices. It is also seen that the variation in insertion loss with respect to temperature variations is negligible for the test device **610**. On the other hand, insertion loss introduced by conventional devices changes with temperature variations.

[0036] Figure 8 illustrates the results of a temperature cycle test. This test included heating the test device **610** to 85 degrees Celsius and then cooling it to -40 degrees Celsius. The temperature cycle test also included subjecting a conventional-type device as described above to the test.

[0037] In Figure 8, a temperature curve **802** is shown in terms of Celsius degrees with respect to time. A first test device curve **806** represents the performance of the first test device **610** and is shown in terms of insertion loss with respect to the temperature curve **802** and time. A second test device curve **808** represents the performance of a second test device **610** and is shown in terms of insertion loss with respect to the temperature curve **802** and time. A conventional device curve **804** represents the performance of the conventional-type device and is evaluated in terms of insertion loss with respect to the temperature curve **802** and time. In the chart of Figure 8, insertion loss is evaluated in terms of decibels (dB) and time is evaluated in terms of minutes (min).

[0038] Similar to the soak test, the first test device curve **806** and the second test device curve **808** reveal less insertion loss due than the conventional device curve **804** as indicated by the insertion loss values at zero minutes. However, significantly, as the temperature varies over time, the conventional device curve **804** shows an insertion loss that varies with the change in temperature **802**, whereas the first test device curve **806** and the second test device curve **808** show

no such correlation by maintaining a substantially consistent value of insertion loss.

[0039] The results of the temperature cycle test reveal that devices constructed in accordance with the test device **610** are more effective at limiting device-induced insertion loss introduced to a fiber optic system than are conventional devices. For example, the insensitivity of the insertion loss during thermal cure of the adhesive during the first part of the thermal soak test illustrates that that fiber optic devices constructed in accordance with the teachings herein better limit the negative effects of adhesive shrinkage than do conventional techniques. Additionally, the results of the temperature cycle test clearly indicate that the magnitude of insertion loss induced by conventional devices varies with changing temperatures. The results of the temperature cycle test also clearly indicate that the amount of insertion loss induced by a device constructed in accordance with the test device **610** remains substantially consistent regardless of temperature or changes thereof.

[0040] Figure 9 illustrates the steps for one embodiment of the method of adhering optical elements in accordance with the present invention. The first step is aligning **902** the optical element **106**, **108** relative to the housing **102** or substrate **602**, **604** for minimum insertion loss. The second step is to apply the adhesive **904**. In one embodiment, the adhesive is applied to longitudinal slots on opposing sides of the optical element. The slots are formed in a housing **102**, or, in another embodiment, the slots are formed in one or more substrates **602**, **604**. The third step is curing **906** the adhesive **302**, **304**.

[0041] In one embodiment, the aligning step **902** is performed with a high-precision robot that actively aligns the optical element **106**, **108** by using the intensity of an optical signal as feedback and moving the optical element **106**, **108** to maximize the optical signal strength or intensity. The robot maintains the alignment of the optical element **106**, **108** relative to the support member during the application of adhesive step **904** and the curing step **906**.

[0042] The disclosed adhesive system includes various functions. The function of supporting the optical element **108** is performed by the support member **102**. In various embodiments, the support member **102** is the housing **102** or a pair of substrates **602**, **604**. The function of adhering said optical element to the means for supporting is performed, in one embodiment, by the adhesive **302** in a slot **112** in the support member **102**, with the adhesive contacting the optical element **108**. In another embodiment, the function of adhering is performed by the adhesive **302**, **304** in opposing slots **112A**, **112B** in the support member **102**, with the optical element **108** interposed between the slots **112A**, **112B**.

[0043] From the foregoing description, it will be recognized by those skilled in the art that an adhesive system for securing optical elements has been provided. The adhesive is not intended to be placed in the optical path. Instead, the adhesive system secures optical elements to a housing or substrate in an aligned position that is maintained over widely varying environmental conditions. The adhesive system includes an optical element, typically cylindrically shaped, but it may have planar surfaces, a housing or substrate to which the optical element is to be secured or fixed, and an adhesive. The adhesive includes a filler of amorphous silica and shrinks very little when cured and is dimensionally stable over a wide temperature range.

[0044] While the present invention has been illustrated by description of several embodiments and while the illustrative embodiments have been described in considerable detail, it is not the intention of the applicant to restrict or in any way limit the scope of the appended claims to such detail. Additional advantages and modifications will readily appear to those skilled in the art. The invention in its broader aspects is therefore not limited to the specific details, representative apparatus and methods, and illustrative examples shown and described. Accordingly, departures may be made from such details without departing from the spirit or scope of applicant's general inventive concept.